USER'S GUIDE

Establishing Longleaf Pine Seedlings Under a Loblolly Pine Canopy

SERDP Project RC-1474

FEBRUARY 2017

Joan L. Walker
G. Geoff Wang
Clemson University

Benjamin O. Knapp
University of Missouri

Huifeng Hu
Institute of Botany, Chinese Academy of Sciences

SERDP
DOD ▪ EPA ▪ DOE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01/02/2017

2. REPORT TYPE
User's Guide

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
User's Guide: Establishing Longleaf Pine Seedlings Under a Loblolly Pine Canopy

5a. CONTRACT NUMBER
W912HQ-06-C-0053

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Joan L. Walker, G. Geoff Wang - Clemson University

Benjamin O. Knapp - University of Missouri

Huifeng Hu - Institute of Botany, Chinese Academy of Sciences

5d. PROJECT NUMBER
RC-1474

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Clemson University
233 Lehotsky Hall
Clemson, SC 29634

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research and Development Program
4800 Mark Center Drive
Suite 17D03
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT
The purpose of this report is to provide management recommendations developed from research on establishing longleaf pine within loblolly pine stands. The recommendations focus on canopy management and cultural practices to favor longleaf pine seedling establishment and early growth. The report provides foresters and managers information relevant to regenerating longleaf pine without removing the entire loblolly pine canopy, i.e., without clearcutting.

15. SUBJECT TERMS
Longleaf pine, loblolly pine stands, canopy management, seeding establishment.

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dr. Joan Walker
					19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	UU	UL	28	864-656-1407

Page Intentionally Left Blank

Page Intentionally Left Blank

TABLE OF CONTENTS

List of Figures

List of Tables

1. PURPOSE AND ORGANIZATION

The purpose of this report is to provide management recommendations developed from research on establishing longleaf pine within loblolly pine stands. The recommendations focus on canopy management and cultural practices to favor longleaf pine seedling establishment and early growth. The report provides foresters and managers information relevant to regenerating longleaf pine without removing the entire loblolly pine canopy, i.e., without clearcutting.

Following an introduction that addresses the motivation and significance of under-planting longleaf seedlings (Section 2), the report provides guidelines for applying research results, beginning with information about where and under what conditions the guidelines apply (Section 3). Section 4 contains specific guidelines for preparing the loblolly canopy for under-planting, as well as a discussion of factors to be considered when deciding how to proceed. Management practices associated with seedling establishment (site preparation, planting, and post-planting treatments) are presented and related to widely accepted silvicultural practices for longleaf pine regeneration (Section 5). Appendix 1 provides a brief project description with details of experimental treatments.

2. BACKGROUND

2.1. Why plant longleaf pine seedlings under a loblolly pine canopy?

Many landowners are interested in restoring native longleaf pine forests (Figure 1) for the diverse values they provide. These forests afford abundant recreational opportunities like hiking, bird-watching, hunting, and off-road vehicle use, and yield valuable products including quality saw-timber and pine needles for landscaping. Longleaf pines are resistant to common forest insects and hurricanes and other wind events, and can be managed economically with prescribed fire. However, many forested lands that might be considered for restoration have been converted to pine species with faster early growth and better apparent establishment success, such as loblolly pine (Figure 2). These sites often have hardwoods in the midstory and ground layer. Where landowners want to convert loblolly pine to longleaf pine, traditional approaches would indicate clearcutting followed by planting longleaf seedlings. Even if conversion to longleaf pine is desired, an existing loblolly pine canopy could be providing current value that the landowner does not want to forfeit. For example, if the loblolly stand is young, premature harvest would reduce the landowner's return on investment needed to establish it. An extant loblolly pine canopy also drops needles that facilitate prescribed fire—a management treatment that provides economical control of hardwoods and helps maintain an herbaceous ground cover.

Figure 1. Longleaf pine forest well-maintained with frequent burning. (Brunswick County, NC)

Figure 2. Loblolly pine on a site historically dominated by longleaf pine. (Dorchester County, SC)

On many public lands, managers may be required to maintain a mature pine habitat for the red-cockaded woodpecker (RCW), a species protected by the Endangered Species Act. Although longleaf pine forests provide the preferred RCW habitat, there are many RCW populations that currently rely on loblolly pine, including RCWs on some U.S. Department of Defense (DoD) properties. In such situations, loblolly canopy harvest may be restricted in order to meet the habitat guidelines established in the species recovery plan (U.S. Fish and Wildlife Service 2003). The foraging habitat guidelines specify characteristics of the pine canopy structure, the abundance of hardwoods in the canopy and midstory, and even the condition of the ground layer vegetation (Table 1). For managing loblolly forests occupied by the RCW, ideal strategies include restoring longleaf pine dominance without eliminating the established loblolly pine canopy, improving the ground layer composition, and facilitating the use of prescribed fire.

Table 1. Characteristics of RCW foraging guidelines established in the species recovery plan (U.S. Fish and Wildlife Service 2003).

Structural feature	Description	Required criteria
Canopy pines	>60 years in age and ≥35 cm DBH	At least 45 TPH and 4.6 m^2/ha BA
	25.4 cm > DBH > 35 cm	0–9.2 m^2/ha BA
	<25.4 cm DBH	<50 TPA and 2.3 m^2/ha BA
	All pines ≥25.4 cm DBH	>9.2 m^2/ha BA
Midstory	Hardwoods	<2.1 m tall
Ground layer	Grasses and herbaceous cover	≥40% cover
	Fine fuel contribution	Sufficient to carry fire every 5 years

BA – basal area, cm – centimeter(s), DBH – diameter at breast height, ha – hectare(s), m – meter(s), m^2 – square meter(s), TPA – trees per acre, TPH – trees per hectare

2.2. Is it possible to establish a longleaf pine stand without clearcutting?

Naturally regenerating longleaf pine forests typically develop as an uneven-aged mosaic of even-aged patches. Natural regeneration is commonly observed within canopy gaps, and frequent lightning strikes or other small scale disturbance events often create favorable conditions for natural regeneration (Figure 3). The natural regeneration process suggests the potential for uneven-aged management and for regenerating longleaf in the presence of mature trees. Indeed, the success of the “Stoddard-Neel” management system provides evidence that uneven-aged management approaches can be used for managing longleaf pine, and lends support to under-planting with canopy manipulation in other pine stands. (The silvicultural method used in the Stoddard Neel system resembles “thinning from below” [Moser et al. 2002], and the key features include maintaining densities <15 square meters [m^2] basal area [BA]/hectare [ha] [40 square feet (ft^2) BA/acre (ac)], managing the overstory with removal from below, maintaining a reproduction component in the stand [i.e., in gaps] and allowing transition from reproduction to overstory on some small proportion of the area.)

Figure 3. Patch of natural regeneration growing in a canopy opening. (Apalachicola NF, FL)

Regenerating longleaf pine stands using a shelterwood system has proven successful. In this system, the existing longleaf pine canopy is reduced to a low BA (5–8 m^2/ha, 25–30 ft^2/ac; Dennington and Farrar 1991), leaving the best trees to produce seed for the next generation. After new seedlings are established, the retained canopy (overwood) is generally removed, leaving an even-aged developing stand. Following establishment, overwood removal eliminates potential negative effects of a canopy on the developing regeneration. Variations of this system, including retaining the overwood through the growth of the new cohort (irregular shelterwood), is possible, resulting in a two-aged stand. The successful longleaf pine regeneration using shelterwood methods supports the expectation that under-planting in loblolly stands may be possible.

Previous studies of alternative silvicultural methods for regenerating longleaf pine have shown that seedling growth is reduced by the presence of canopy trees. One study documented that seedling size increased substantially with <8 m^2/ha (35 ft^2/ac) of overstory BA (Palik et al. 1997). Others have studied the growth of naturally established and planted longleaf pine seedlings in canopy gaps of various sizes (e.g., Palik et al. 2003, McGuire et al. 2001). These studies recommend minimum gap sizes of 0.1–0.2 ha (0.25–0.5 ac) to minimize competition with the surrounding longleaf pine canopy. The well-documented interaction between a longleaf pine overstory and planted longleaf seedlings may or may not resemble the relationships in loblolly stands.

Establishing longleaf seedlings under loblolly pine rather than longleaf pine presents distinct challenges. Loblolly trees produce abundant seeds that germinate and rapidly reach heights that can shade out longleaf pine seedlings established at the same time. Additionally, loblolly pines have different root distributions and may compete differently than longleaf pine with planted seedlings. Light environments might also differ under longleaf and loblolly pine canopies. There has been little formal research conducted to determine how or if it is possible to gradually convert a loblolly forest to longleaf pine dominance by planting longleaf pine seedlings under intact or partially retained loblolly pine canopies.

2.3. Guidance needed for converting loblolly pine stands to longleaf pine dominance

The Strategic Environmental Research and Development Program (SERDP—a research program of the DoD, U.S. Department of Energy [DOE], and the U.S. Environmental Protection Agency [EPA])[1] funded a project (RC-1474 "Managing declining pine stands for the restoration of red-cockaded woodpecker habitat") to develop silvicultural guidelines for planting longleaf pine under loblolly pine on ecologically suitable sites. In addition to maintaining desirable forest structure for training, an important consideration for the DoD managers is to provide habitat for the RCW.

The study was conducted on Marine Corps Base Camp Lejeune, NC, and Fort Benning, GA/AL (Figure 4). The project included a field experiment in which the canopies of mature loblolly pine stands were reduced by cutting either small groups of trees to create gaps or by cutting individual trees to reduce loblolly pine BA uniformly throughout the stand. Initial BAs in experimental sites were >14 m^2/ha (~60 ft^2/ac). Uncut areas served as experimental controls; experimental treatments included areas with BA ~4–5 m^2/ha (~25 ft^2/ac, low BA), ~ 8–9 m^2/ha (~40 ft^2/ac, medium BA), clearcut (0 m^2/ha BA), 0.1 ha (0.25 ac) gaps, 0.3 ha (0.75 ac) gaps, and 0.5 ha (1.25 ac) gaps (Figure 5). The study also included herbicide and combined herbicide-fertilizer treatments that might benefit planted longleaf pine seedlings after planting. In addition to measuring longleaf pine seedling survival and growth through five years, changes in the midstory abundance, ground layer vegetation, and fire behavior were measured. Details of the experimental design and results on which the recommendations are based are available as peer-reviewed publications (see Section 6), the final report for the RC-1474 project,[2] and Appendix 1 of this report.

[1] https://serdp-estcp.org.

[2] https://www.serdp-estcp.org/content/search?cqp=Standard&SearchText=Final+Report+RC-1474&x=39&y=6.

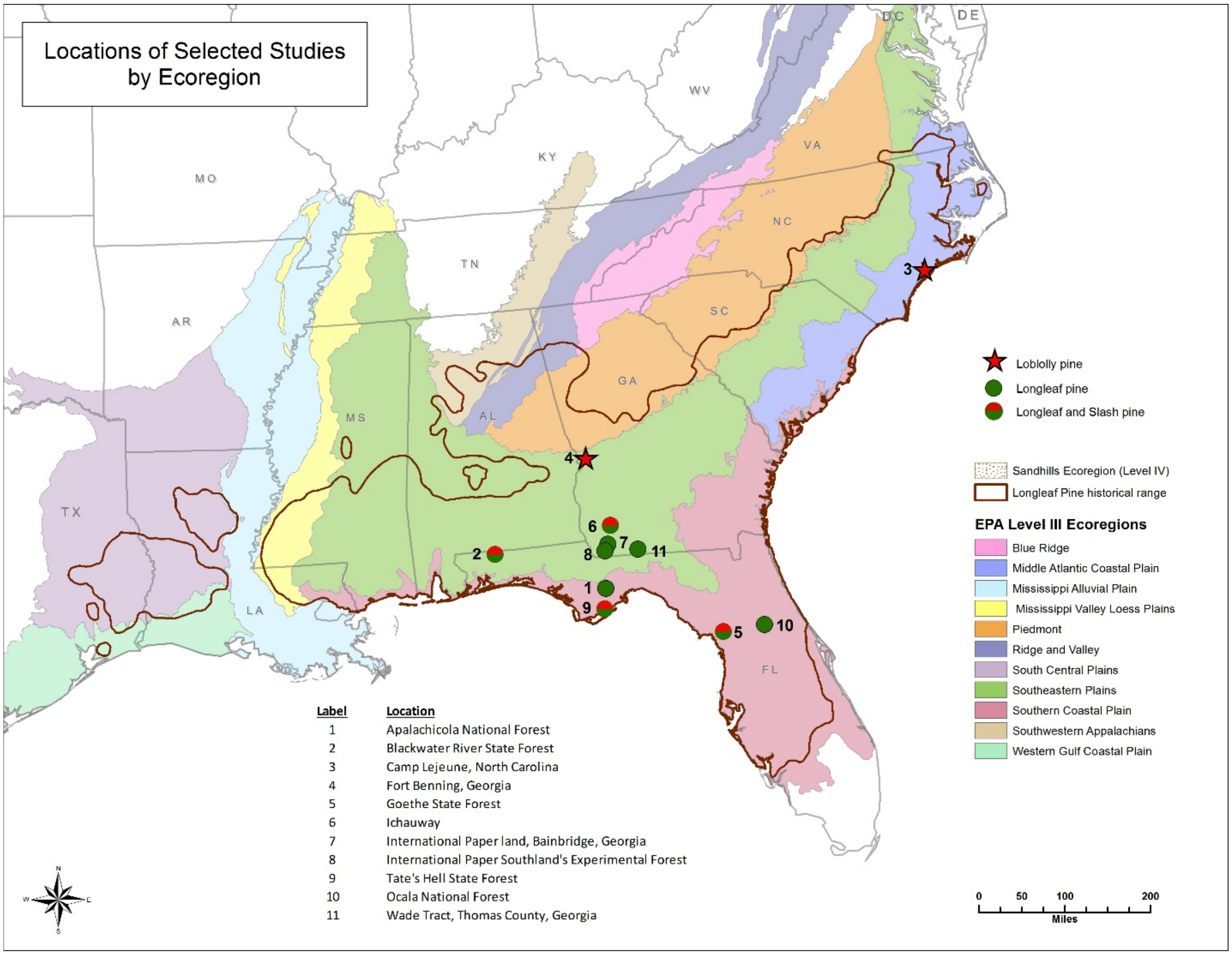

Figure 4. Locations of research studies of longleaf pine regeneration with partial canopy retention.

The SERDP-sponsored study (RC-1474) located at Camp Lejeune, NC (site #3) and Fort Benning, GA (#4), is the only study conducted in loblolly pine stands. Of the other studies, four were conducted in a slash pine or mixed slash/longleaf pine stands (#s 2, 5, 6, 9); all others were studies of longleaf pine seedlings established under longleaf pine canopies. The historical range of longleaf pine and EPA Level III Ecoregions are shown for reference. Among these studies, there is agreement on effects of canopy management on longleaf pine seedling survival and early growth.

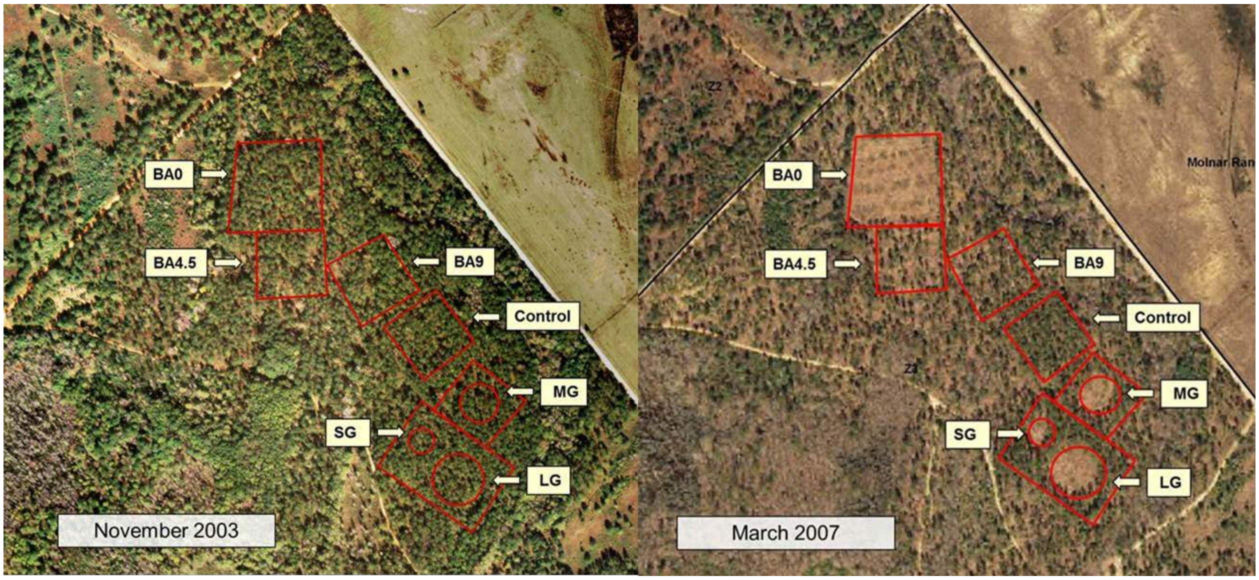

Figure 5. Canopy treatment areas pre- and post-harvest (left, right panels, respectively).

Experimental canopy conditions were created in mature loblolly pine stands. Large more or less homogeneous stands were identified and treatment areas arranged for the best fit (left panel). Harvests were contracted and managed by local installation personnel in accordance with management guidelines. Canopy harvest and site preparation were completed in 2007, and container grown seedlings were planted in January 2008.

Establishing a cohort of longleaf pine seedlings is the start of converting a stand from loblolly to longleaf pine dominance, but additional treatments are needed to ensure that the longleaf trees eventually dominate the stand. The planned activities (silvicultural system) to assure eventual longleaf dominance can generally be divided into three groups of treatments (Figure 6): harvest, regeneration, and intermediate. The treatment choices in these groups are not independent; harvest choices influence the kinds of regeneration and intermediate treatments needed. The research focused on harvest and regeneration treatments, but choices among available options will affect the intermediate treatment requirements and the ability to achieve long-term management goals. (See Section 4.1 for more on this topic.)

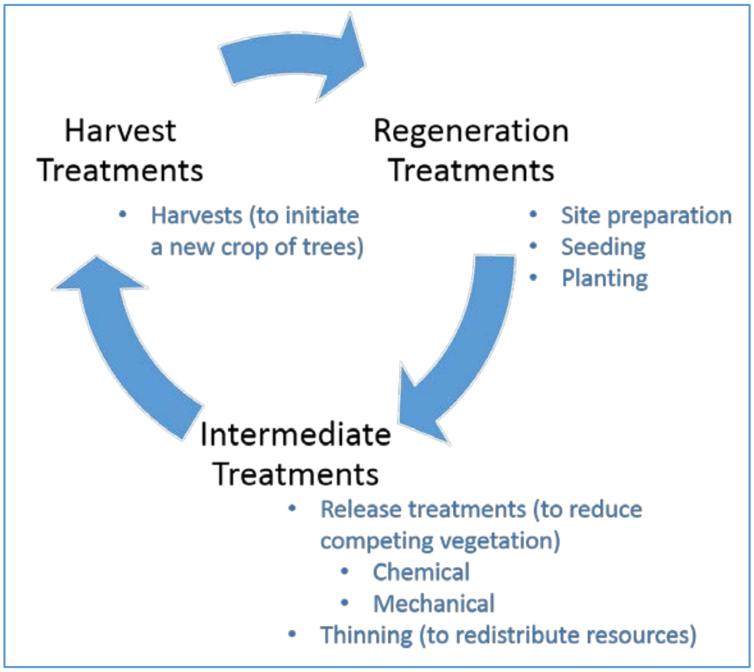

Figure 6. Kinds of silvicultural treatments applied in managing forest stands to ensure the regeneration of the next generation of trees.

Treatment choices at each stage are not independent; harvest choices influence the kinds of regeneration and intermediate treatments needed.

3. WHERE DO THE GUIDELINES APPLY? GEOGRAPHIC, EDAPHIC, AND STAND STRUCTURE CONSIDERATIONS

Other studies from different locations in the region where longleaf pine seedlings were experimentally planted under longleaf or slash pines canopies (Mitchell et al. 2006, Kirkman et al. 2007, Pecot et al. 2007) were reviewed, and found agreement on the effects of canopy management on longleaf seedling establishment and early growth. Among the studies, this study is the only one conducted in loblolly pine stands; several were conducted in a slash pine or mixed slash/longleaf pine stands (Figure 4: #s 2, 5, 6, 9); all others focused on longleaf pine seedlings established under longleaf canopies. Based on this review, these guidelines for seedling establishment and early growth in a loblolly stand are likely applicable across most of the longleaf pine range (Figure 4). The canopy management guidelines should be applicable on properties located in the Middle Atlantic Coastal Plain, Southeastern Plains, the northern half of the Southern Coastal Plain EPA Level III Ecoregions, as well as the Sandhills Level IV Ecoregion. Assuming that light availability is a key determinant of longleaf pine seedling establishment throughout its geographic range, it is believed the canopy guidelines will prove applicable in the western longleaf pine range and in mountain longleaf pine sites (the South Central Plains, the Piedmont, and Ridge and Valley Level III Ecoregions).

Site suitability for managing longleaf pine is strongly related to soil quality. This study was conducted on soils and sites where local managers intended to restore longleaf pine, including soils ranging from moderately wet fine sands and loamy sands to well-drained sands, sandy loams, and sandy clay loams.

For applying the results, it was assumed local land managers understand which soils and sites are suitable for longleaf pine, and will choose sites considered suitable for longleaf pine. It was noted that soil characteristics could affect results in two major ways. First, on well-drained soils, drought conditions may result in higher seedling mortality than on less well-drained soils (Rodriguez-Trejo et al. 2003). Secondly, on sites that are especially favorable to loblolly pine, greater effort will be needed to limit the negative effects loblolly seedlings can have on planted longleaf pine seedlings (Brockway et al. 2005). No studies have been conducted on lands with a recent history of tillage agriculture. With increasing but insufficient understanding of how native species establish and grow on old agricultural lands within the longleaf pine range (Brudvig et al. 2013; Veldman et al. 2014), it is not certain that outcomes on those sites will be comparable to previously published results. More research is needed on the restoration of such sites.

Finally, study areas varied in initial loblolly pine density and tree size. Initial densities were >~14 m^2 BA/ha (~60 ft^2/ac; range: 11–22 m^2/ha, 48–96 ft^2/ac) and pre-treatment mean canopy tree diameter at breast height (DBH) ranged from 22–42 centimeters (cm) (8.5–16.5 inches). The experimental treatments created comparable light conditions, regardless of starting densities. Because light was the resource most strongly associated with growth, the pre-thinning initial densities in the study did not affect early seedling performance. In general, it is believed that the thinning guidelines will apply to any initial density. It is recognized, however, that at a given target BA, the condition under which the longleaf seedlings are planted will differ depending on the initial mean tree diameter: fewer, larger stems versus more, smaller stems. More closely-spaced residual canopy trees could close the canopy over planted seedlings more quickly than more widely-spaced trees, thereby requiring intermediate tree removal. However, the effects of this difference are unknown, and deserve additional study.

4. HARVEST TREATMENTS TO REDUCE THE LOBLOLLY PINE CANOPY

The loblolly canopy was reduced using two distinct approaches: removing trees uniformly throughout the stand to reach a target residual canopy density (BA), and creating gaps by harvesting groups of trees in patches. Based on the performance of planted seedlings and effects on groundlayer vegetation and prescribed fire behavior, guidelines were developed for both approaches.

For planting uniformly, harvest canopy trees leave a residual BA between 5 and 8 m^2/ha (~25–35 ft^2/ac). Research results indicated that forests with residual canopy BA in this range showed favorable responses for seedling establishment and growth, midstory control, and desirable prescribed fire behavior. Below 8 m^2/ha (~35 ft^2/ac), seedling growth reductions were moderate and did not inhibit grass stage emergence. Above 5 m^2/ha (~25 ft^2/ac), canopy cover reduced the growth rate of competing hardwood and loblolly pine midstory. At one site (Fort Benning), residual canopy at this level reduced seedling mortality compared to mortality in a clearcut—a beneficial effect shown in previous studies and attributed to reducing moisture stress during drought years. Finally, with BA >5 m^2/ha (25 ft^2/ac), the canopy trees produced enough needlefall to carry fire throughout the stand.

For planting into gaps, canopy trees should be removed to create small gaps (0.1 ha, radius ~18 meters [m]; 0.25 ac, radius ~60 feet [ft]). In gaps as small as this, planted seedlings achieved maximum growth rates (comparable to growth in clearcuts) in the gap centers. In larger gaps, seedlings did not grow any

faster, but the area with conditions suitable for maximum growth was greater. Areas suitable for maximum seedling growth also favored vigorous midstory growth and abundant loblolly pine regeneration—a negative consequence of larger gaps. It was found that canopy pines surrounding such small gaps cast enough needles to carry prescribed fires through. On balance, creating 0.1 ha (0.25 ac) openings is recommended, especially where loblolly seedfall and vigorous growth are expected.

Canopy retention in either form results in some loss of seedling performance compared to planting into clearcut conditions (Table 2). Outcomes were similar between study sites, except for first-year longleaf pine seedling survival. Seedling mortality in clearcuts and low levels (~5 m^2/ha; ~25ft^2/ac) of canopy retention was comparatively high at Fort Benning, presumably due to drought stress during the first growing season. Mean survival and growth were similar across all gap sizes in both sites, and were not significantly different between small gaps (0.1 ha) and clearcut conditions. Managers should anticipate reduced growth relative to clearcuts with recommended canopy densities (Figure 7); however, this reduced growth may be an acceptable trade for gains in controlling competition and production of pine needles to support prescribed fire through a stand.

Table 2. Seedling responses expected through five years in recommended canopy management treatments.

	Canopy treatment			
Response	Clearcut	~ 5 m^2/ha (~25 ft^2/ac)	~8 m^2/ha (~35 ft^2/ac)	≥0.1 ha (0.25 ac) gap
% Survival (5 yr)	(40*) ~80	(50*) ~80	60–70	~50
Root collar diameter	35–40 mm	30–32 mm	25–30 mm	30–35 mm
% height growth	~85–60	~60–45	~45–25	~65–40
**Probability of individual seedling in height growth	0.8	.8–.6	.6–.45	

mm – millimeter(s)

Clearcut treatment results from this study are provided for reference. These results are included to show relative effects of canopy treatments. Site-specific results are likely to vary with local conditions and from year to year, but treatment differences should be similar.

*The lower values (in parenthesis) represent the high mortality in Year 1 of the project at Fort Benning, likely related to drought conditions during the season following planting.

**Calculation based on logistic modeling of individual seedling responses for those seedlings alive at Year 5.

Figure 7. Exceptional five-year sapling in Large Gap (left panel); typical five-year seedling starting height growth under a loblolly pine canopy with 5 m^2 BA/ha (25 ft^2/ac).

4.1. Uniform thinning or gap creation? Factors to consider

The initial choice between planting throughout a uniformly harvested stand and planting in gaps fixes the distribution of regeneration (longleaf seedlings) relative to the retained loblolly pine matrix. The arrangement has consequences for intermediate stand management and for the long-term stand structure. Both the landowner’s capacity to conduct required intermediate treatments and the landowner’s intermediate and long-term management objectives should be considered in making this initial choice.

Intermediate management treatments to ensure the growth of planted longleaf pines

Intermediate management will be needed to control the negative competitive effects of residual canopy trees, loblolly ingrowth, and hardwoods and shrubs on planted longleaf seedlings and saplings. Typical treatments to manage these effects include additional harvest, prescribed fire, and herbicides, respectively. The arrangement of regeneration within the stand may interact with site quality and affect the need and feasibility of these operations.

Given time, all seedlings in uniformly thinned stands are likely to be negatively affected by residual loblolly trees to varying degrees, with longleaf trees nearer or directly underneath a mature loblolly stem growing more slowly than more distant ones. Intermediate harvests to make more resources available to suppressed longleaf will involve cutting trees throughout the stand, potentially damaging planted longleaf. By contrast, seedlings planted in the centers of gaps will experience little or no suppression by canopy trees for an extended period of time, perhaps long enough to capture canopy space. As residual loblolly trees grow into the gap, however, intermediate harvests could be located on gap edges minimizing loss by harvest operations. Additional canopy harvest to favor the developing longleaf cohort will be needed sooner in sites favorable to loblolly growth compared to sites less favorable to loblolly growth, and among younger loblolly canopies compared to older loblolly canopies. Given these considerations, on sites that favor loblolly pine (generally higher productivity sites), gap

regeneration may be more successful. In conditions where residual trees grow more slowly, uniform thinning and under-planting should support successful establishment throughout the stand.

Prescribed burning is required, especially to control loblolly ingrowth from local seedfall. Site quality will influence the success of loblolly ingrowth, but it will occur on all sites with mature loblolly trees. In uniformly thinned stands, both needle cast and groundlayer fine fuel production should be sufficient to carry fire through the stand (with an appropriate burning prescription). Fire behavior in stands with cut patches may be more variable, with lower groundlayer fuel production in the untreated loblolly matrix and abundant fuel in gaps. The number and distribution of the cut patches will influence fire behavior, and might be managed to ameliorate fire suppression under the loblolly canopy. Another option may be to thin the loblolly matrix to some intermediate density (e.g., 40 ft^2/ac) to support fine fuel production between planted gaps.

Loblolly will grow rapidly in gap centers necessitating more frequent burning to maintain the longleaf advantage in gaps. Similarly, loblolly seedlings will grow more rapidly on favorable sites, where more frequent burning may be needed. If frequent burning is not possible, then uniform thinning may provide a better option by virtue of its partial control of loblolly pine ingrowth. On wetter sites where loblolly growth is vigorous, and where the ability to burn regularly and frequently is constrained, conversion with partial loblolly pine canopy retention may not be feasible.

Several factors may affect the need for intermediate hardwood control treatments. The kind and rate of hardwood growth (including trees and shrubs) will be influenced by site quality and the degree of control or elimination during site preparation and planting. Establishing conditions that facilitate fire management prior to beginning conversion is a strategy that has worked for some managers (Figure 8). The arrangement of longleaf regeneration will not likely affect the need for hardwood control; however, if longleaf regeneration is concentrated in patches, treatments may be concentrated and more efficiently implemented.

Figure 8. Longleaf pine seedlings growing under a loblolly pine canopy (Beaufort County, SC). (Photo: R. Costa)

Prior to reducing the canopy to about 35 ft^2/ac, managers burned the site frequently and continue to do so. A continuous herbaceous ground cover was established before container-grown longleaf seedlings were planted.

Landowner objectives inform the initial planting arrangement

The initial planting pattern will persist through stand development; when the longleaf pines attain canopy positions, they will be distributed throughout or concentrated in groups. Landowner objectives, e.g., for aesthetic values, habitat quality, or economic return, may be more or less consistent with one of the other arrangements. The desired stand structure should be explicitly considered at the beginning of the project as part of the long-term management plan.

5. REGENERATION TREATMENTS

Results related to site preparation, planting, and early management, specifically chemical release treatments to eliminate competition after planting and prescribed burning, were consistent with widely accepted silvicultural practices for longleaf pine regeneration (Addington et al. 2012, Haywood 2011, Freeman and Jose 2009, Knapp et al. 2006, Dennington and Farrar 1991). This section includes key practices and assumes that managers using these guidelines are familiar with regenerating longleaf pine.

5.1. Site preparation

Prior to planting, the stand should be prepared based on site-specific needs, with particular attention to reducing competing vegetation. Results of this study and others showed that the amount and kind of competition that develops is strongly dependent on what vegetation remains after site preparation. Early control is needed to ensure seedling growth.

5.2. Planting

Planting should include container-grown seedlings at densities needed to ensure target stand densities after expected early mortality. Based on previous work, planting densities for establishing longleaf pine stands in clearcuts range from 494–1,483 trees per hectare (TPH; 200–600 trees per acre [TPA]), although arguments for planting <500 TPA have been made (South 2006, and included references). Mortality rates observed under thinned canopies or in small gaps in this study ranged from ~30% to 50% (five-year), well within the ~10%–~75% (three-year) range reported for container-grown longleaf pine planted into clearcuts across a range of sites (South et al. 2005).

5.3. Early management (seedlings in the grass stage, and early height growth)

Controlling competing vegetation during establishment is essential. Results showed longleaf pine seedling growth and emergence from the grass stage during the first five seasons increased with herbicide release treatments applied to reduce competing vegetation, although chemical release did not affect the five-year survival rate. The control methods needed will vary with the amount and kind of vegetation present prior to harvest and condition post-site preparation. If hardwood vegetation develops, herbicides can be used to reduce midstory stems. A variety of herbicides to control woody vegetation can be applied over longleaf pine seedlings with minimal negative effects on pine seedlings; specific formulations should be based on the type of competing vegetation to be controlled. Consulting a professional forester or vegetation management specialist for a site evaluation and site-specific prescription is recommended.

Post-planting herbicide treatments as used in the research project for direct foliar application targeting woody vegetation at both Camp Lejeune and Fort Benning (Appendix 1) reduced midstory development as expected. This effect was associated with increased growth of planted seedlings and a higher rate of emergence from the grass stage. The experimental herbicide treatment targeted developing woody species, and resulted in greater herbaceous species cover and reduced woody species cover in the ground layer. This shift produced more fine fuels and supported desirable prescribed fire behavior (increased proportion of the area burned). Although herbaceous cover increased, neither site achieved the 40% herbaceous cover specified in the RCW foraging habitat guidelines.

On sites with abundant herbaceous vegetation, herbaceous control may improve longleaf pine seedling establishment (Haywood 2005), although this study was not designed to differentiate between herbaceous and woody competition. Where local herbaceous competition control is needed, band or spot applications, as used in the study (Appendix 1), can be used to localize effects around longleaf pine seedlings and to minimize stand-level effects on desired herbaceous vegetation. Researchers and practitioners continue to test treatment options to determine which can balance necessary weed control with minimizing effects on desired native plant species, but there is no definitive synthesis of

studies on general consensus among practitioners. Professional site evaluation for prescription development is recommended.

Fertilization does not favor longleaf pine growth or survival and it is not recommended. Nutrient additions in the study resulted in undesirable survival and growth of loblolly pine regeneration.

It is necessary to burn under-planted stands frequently, as often as every two to three years on mesic productive sites, and throughout stand development. Frequent burning is essential for controlling loblolly pine regeneration. There is currently no chemical alternative that can be applied to target loblolly pine without harming planted longleaf pine seedlings. Results confirmed that the probability of a loblolly pine surviving prescribed fire increases with size (becoming resistant at about 4 m [12 ft] tall), but stems of all sizes may be killed. In some cases, especially in gaps where the canopy is removed completely or on wetter sites where loblolly pines grow rapidly, the fire return interval may have to be shortened or additional mechanical treatments may be required to control loblolly pine regeneration, with the potential risk of damage to planted longleaf pine seedlings.

Many studies have shown that frequent burning generally increases herbaceous ground cover and reduces or maintains the low stature of shrubs in the ground layer. This condition, in turn, facilitates subsequent burning. Shifting from predominantly woody vegetation to grass and herb dominance may require many fires; however, shrub size will be reduced after one to few fires.

It will be necessary to apply prescribed fire throughout stand development. Abundant loblolly recruitment was observed each year of the study, with significantly more loblolly regeneration at Camp Lejeune than Fort Benning. Previous research suggests that loblolly seed crops may be more reliable and larger at coastal plain sites compared to inland locations, and such a difference in seedfall may have contributed to an unknown degree to the observed site differences in loblolly regeneration.

6. SUMMARY

The best available science indicates that managers can successfully establish longleaf pine seedlings under or within a loblolly pine stand, if (1) the canopy is first reduced by uniform thinning to 5–8 m^2/ha (25–35 ft^2/ac) and planting container-grown seedlings throughout, or by creating gaps of area at least 0.1 ha (0.25 ac) and planting seedlings into the canopy openings; and (2) competition from herbaceous or woody vegetation and from loblolly seedling ingrowth is minimized. In choosing between uniform thinning or gap regeneration, managers must consider their capacity to do intermediate management, and keep in mind that long-term goals may be more or less compatible with each approach.

Ensuring successful conversion will require identifying and implementing necessary intermediate treatments, such as minimizing midstory development and ingrowth of loblolly pine. Regular and frequent prescribed burning is essential (Figure 9). Additional canopy tree removal may be needed if residual loblolly pine canopies expand into canopy openings and suppress established longleaf saplings and trees.

Figure 9. Prescribed burning is essential for controlling loblolly pine regeneration.

Research results suggest that successful conversion using under-planting will not be possible on sites where frequent prescribed fire cannot be used. The capacity to burn frequently must be evaluated carefully.

7. REFERENCES

7.1. Project publications

Hu, H., Wang, G.G., Walker, J.L., and Knapp, B.O. 2012a. Silvicultural treatments for converting loblolly pine to longleaf pine dominance: Effects on resource availability and their relationships with planted longleaf pine seedlings. *Forest Ecology and Management* 282: 115-123.

Hu, H., Wang, G.G., Walker, J.L., and Knapp, B.O. 2012b. Silvicultural treatments for converting loblolly pine to longleaf pine dominance: Effects on planted longleaf pine seedlings. *Forest Ecology and Management* 276: 209-216.

Hu, H., Knapp, B.O., Wang, G.G., and Walker, J.L. 2016. Silvicultural treatments for converting loblolly pine to longleaf pine dominance: effects on ground layer and midstory vegetation. *Applied Vegetation Science* 19: 280-290.

Knapp, B.O., Wang, G.G., Hu, H., Walker, J.L., and Tennant, C. 2011. Restoring longleaf pine (*Pinus palustris* Mill.) in loblolly pine (*Pinus taeda* L.) stands: Effects of restoration treatments on natural loblolly pine regeneration. *Forest Ecology and Management* 262(7): 1157-1167.

Knapp, B.O., Wang, G.G., and Walker, J.L. 2013. Effects of canopy structure and cultural treatments on the survival and growth of *Pinus palustris* Mill. seedlings underplanted in *Pinus taeda* L. stands. *Ecological Engineering* 57: 46-56.

Knapp, B.O., Walker, J.L., Wang, G.G., Hu, H., and Addington, R.N. 2014. Effects of overstory retention, herbicides, and fertilization on sub-canopy vegetation structure and functional group composition in loblolly pine forests restored to longleaf pine. *Forest Ecology and Management* 320: 149-160.

Knapp, B.O., Wang, G.G., Walker, J.L., and Hu, H. 2015. From loblolly to longleaf: fifth-year results of a longleaf pine restoration study at two ecologically distinct sites. In: Holley, A.G., Connor, K.F., and Haywood, J.D. (eds.). Proceedings of the 17th Biennial Southern Silvicultural Research Conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. pp. 470-472.

Knapp, B.O., Wang, G.G., Walker, J.L., and Addington, R.N. 2016. Fate of residual canopy trees following harvesting to underplant longleaf pine seedlings in loblolly pine stands in Georgia. *In:* Schweitzer, C.J., Clatterbuck, W.K., and Oswalt, C.M. (eds). Proceedings of the 18th Biennial Southern Silvicultural Research Conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. pp. 60-67.

Knapp, B.O., Wang, G.G., Walker, J.L., and Hu, H. 2016. Using silvicultural practices to regulate competition, resource availability, and growing conditions for *Pinus palustris* seedlings underplanted in *Pinus taeda* forests. *Canadian Journal of Forest Research* 46: 902-913.

Walker, J.L. and G.G. Wang. 2013. Final Report. RC-1474 “Managing declining pine stands for the restoration of red-cockaded woodpecker habitat.” Available on the SERDP Website: https://serdp-estcp.org/Program-Areas/Resource-Conservation-and-Climate-Change/Natural-Resources/Ecological-Forestry/RC-1474 (Accessed October 2016).

7.2. Cited publications

Addington, R.N., Greene, T.A., Elmore, M.L., Prior, C.E., and Harrison, W.C. 2012. Influence of herbicide site preparation on longleaf pine ecosystem development and fire management. Southern Journal of Applied Forestry 36: 173-180.

Brockway, D.G., K.W. Outcalt, J.G. Guldin, W.D. Boyer, J.L. Walker, C.D. Rudolph, R.B. Rummer, J.P. Barnett, S. Jose, J. Nowak. 2005. Uneven-aged management of longleaf pine forests: a scientist and manager dialogue. Gen. Tech. Rep. SRS-78. Asheville, NC: USDA, Forest Service, Southern Research Station. 38 p.

Brudvig, L.A., E. Grman, C.W. Habeck, J.L. Orrock, J.A. Ledvina. 2013. Strong legacy of agricultural land use on soils and understory plant communities in longleaf pine woodlands. *Forest Ecology and Management* 310:944-955.

Dennington, R.W., and Farrar, R.M. 1991. Longleaf Pine Management. USDA Forest Service, Southern Region, Forestry Report R8-FR3, Atlanta, GA.

Freeman J.E. and Jose S. 2009. The role of herbicide in savanna restoration: effects of shrub reduction treatments on the understory and overstory of a longleaf pine flatwoods. Forest Ecology and Management 257: 978-986.

Haywood, J.D. 2011. Influence of herbicides and felling, fertilization, and prescribed fire on longleaf pine growth and understory vegetation through ten growing seasons and the outcome of an ensuing wildfire. New Forests 41: 55-73.

Haywood, J.D. 2005. Effects of herbaceous and woody plant control on *Pinus palustris* growth and foliar nutrients through six growing seasons. *Forest Ecology and Management* 214: 384-397.

Kirkman, L.K., Mitchell, R.J., Kaeser, M.J., Pecot, S.D., Coffey, K.L., 2007. The perpetual forest: using undesirable species to bridge restoration. *Journal of Applied Ecology* 44: 604-614.

Knapp, B.O., Wang, G.G., Walker, J.L., and Cohen, S. 2006. Effects of site preparation treatments on early growth and survival of planted longleaf pine (*Pinus palustris* Mill.) seedlings in North Carolina. Forest Ecology and Management 226: 122-128.

McGuire, J. P., Mitchell, R.J., Moser, E.B., Pecot, S.D., Gjerstad, D.H., and Hedman, C.H. 2001. "Gaps in a gappy forest: plant resources, longleaf pine regeneration, and understory response to tree removal in longleaf pine savannas." Canadian Journal of Forest Research **31**: 765-778.

Mitchell, R. J., Hiers, J.K., O'Brien, J.J., Jack, S.B., Engstrom, R.T. 2006. "Silviculture that sustains: the nexus between silviculture, frequent prescribed fire, and conservation of biodiversity in longleaf pine forests of the southeastern United States." Canadian Journal of Forest Research **36**: 2724-2736.

Moser, W.K., Jackson, S.M., Podrazsky, V. and Larsen, D.R. 2002. Examination of stand structure on quail plantations in the Red Hills region of Georgia and Florida managed by the Stoddard-Neal system: an example for forest managers. Forestry 75:443-449.

Palik, B.J., Mitchell, R.J., Houseal, G., Pederson, N. 1997. Effects of canopy structure on resource availability and seedling responses in a longleaf pine ecosystem. Canadian Journal of *Forest Research* 27: 1458-1464.

Palik, B.J., R.J. Mitchell, S. Pecot, M. Battaglia, and M. Pou. 2003. Spatial distribution of overstory retention influences resources and growth of longleaf pine seedlings. *Ecological Applications* 13:674-686.

Pecot, S.D., Mitchell, R.J., Palik, B.J., Moser, E.B., Hiers, J.K., 2007. Competitive responses of seedlings and understory plants in longleaf pine woodlands: separating canopy influences above and below ground. *Canadian Journal of Forest Research* 37: 634-648.

Rodríguez-Trejo, D.A., Duryea, M.L., White, T.L., English, J.R., McGuire, J., 2003. Artificially regenerating longleaf pine in canopy gaps: initial survival and growth during a year of drought. *Forest Ecology and Management* 180: 25-36.

South, D.B. 2006. Planting longleaf pine at wide spacings. *Native Plants Journal* 7:79-88.

South, D.B., S.W. Harris, J.P. Barnett, M.J. Hainds, D.H. Gjerstad. 2005. Effect of container type and seedling size on survival and early height growth on *Pinus palustris* seedlings in Alabama, U.S.A. *Forest Ecology and Management* 204:385-398.

U.S. Fish and Wildlife Service. 2003. Red-cockaded Woodpecker (*Picoides borealis*) Recovery Plan: *Second Revision*. US Fish and Wildlife Service, Southeast Region, Atlanta, GA. 296 p.

Veldman, J.W., L.A. Brudvig, E.I. Damschen, J.L. Orrock, W.B. Mattingly, J.L.Walker. 2014. Fire frequency, agricultural history and the nultivariate control of pine savanna understorey plant diversity. *Journal of Vegetation Science* 25:1438-1449.

APPENDIX 1. EXPERIMENTAL DESIGN, RESPONSE VARIABLES, DATA ANALYSES: IN BRIEF

At each site, a replicated field experiment with a randomized complete block, split-plot design was installed. Main-plot treatment included canopy manipulation to four levels of residual BA and creation of circular gaps in the following sizes:

(1) Control (uncut, with BA of ~16 m^2/ha);
(2) medium BA (uniform thinning to BA of 9 m^2/ha);
(3) low BA (uniform thinning to BA of 5 m^2/ha);
(4) clearcut (BA of 0 m^2/ha);
(5) small gap (0.1 ha);
(6) medium gap (0.3 ha); and
(7) large gap (0.5 ha).

Split-plot treatment included three levels of cultural treatment applied to improve longleaf pine seedling establishment:

(1) NT (no treatment),
(2) H (herbicide control of woody vegetation with a direct foliar application of 1% imazapyr to woody vegetation), and
(3) H+F (the herbicide treatment combined with 280 kg/ha of 10-10-10 NPK fertilizer).

An additional treatment (granular mix of 63.2% hexazinone and 11.8% sulfometuron methyl at 0.84 kg/ha) was applied in 1-m-wide bands over the seedlings to control herbaceous competition at Fort Benning (FB) only. Harvesting was completed in 2007. Sites were prepared using standard management practices at each installation (FB: herbicide targeting hardwoods followed by prescribed fire; Camp Lejeune [CL]: mulching followed by prescribed burning) (Figure 10).

Figure 10. Camp Lejeune study sites: starting condition (left) and after mechanical site preparation (right).

Note abundant re-sprouting hardwoods. A single herbicide application to control hardwood increased growth in longleaf seedlings.

In January 2008, container-grown longleaf pine seedlings were planted (FB: 1.8 x 3.7 m spacing; CL: 1.8 x 3.0 m spacing) throughout, into each experimental unit. In each 20 m x 20 m split-plot measurement unit, a random selection of 30 longleaf pine seedlings were tagged in May 2008. Seedling survival and measured root collar diameter and seedling height was measured in October 2008, 2009, 2010, and 2012. Seedlings were considered to have emerged from the grass stage and entered active height growth if the terminal bud was ≥15 cm above the root collar. The effects of canopy treatments on the abundance and number of species (richness) in the midstory (number and identity of woody stems >1 m tall and <2 cm diameter at 1.4 m DBH) and in the ground layer vegetation (percent cover of vegetation <1 m tall by functional groups [grasses and grass-like species, forbs, woody species, ferns]) were measured. Changes in light, nutrients, and soil moisture were measured to help determine the causes of canopy treatment effects. Responses were measured annually with the final measurement five years after planting. Sites were burned during the winter following the third growing season. Fire behavior and fuels were quantified. Details of the treatments, measurements, and analyses are published elsewhere (see Project Publications in the References section).

APPENDIX 2. ACRONYMS AND ABBREVIATIONS

ac	acre
BA	basal area; cross-sectional area of trees based on DBH; m^2/ha or ft^2/ac
cm	centimeter(s)
DBH	diameter at breast height
DoD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
ft	foot/feet
ft^2	square foot/feet
ha	hectare
m	meter(s)
m^2	square meter
RCW	Red-cockaded Woodpecker
SERDP	Strategic Environmental Research and Development Program
TPA	trees per acre, a measure of density
TPH	trees per hectare, a measure of density